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Effect of Planting Date, Mepiquat Chloride, and Glyphosate Application to Glyphosate-Resistant Cotton

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ABSTRACT

Management decisions and common misapplication of glyphosate may impact fruiting of glyphosate-resistant (GR) cotton (*Gossypium hirsutum* L.). Experiments were conducted to determine if planting date affected the ability of GR cotton to compensate for fruit loss after misapplication of glyphosate and to evaluate mepiquat chloride's (MC) contribution to fruiting. Field studies were conducted in Rocky Mount, North Carolina, from 2001 to 2003. Treatments included optimum and late planting and a series of five glyphosate, 0.84 kg a.e. (acid equivalent) ha^{-1}, treatments representing recommended and common misapplication timings including a control. The 10 planting date and glyphosate combinations were factored across treatments of MC and no-MC as needed according to growing conditions in 2001 and 2002. All plots were treated with MC in 2003. Optimal-planted cotton produced more than late-planted cotton. Yield was reduced in optimal-planted cotton in 2001 and late-planted cotton in 2001 and 2002 when glyphosate contacted plants after the four-leaf stage. Misapplication of gyphosate did not affect yield in 2003. Yield was improved with MC by 11% in 2001. Bolls were at higher nodes in late-planted cotton and cotton not treated with MC. Glyphosate contact after the four-leaf stage in 2001 and 2002 shifted the fruitload above Node 10. Late planting of cotton decreases opportunities for fruiting compensation when glyphosate reduced early boll retention. Results support previous research showing application methods that allow glyphosate contact to GR cotton plants after the four-leaf stage increase risk of yield reduction regardless of planting date.

Cotton is grown worldwide for the essential commodities of fiber, seed, and oil. Glyphosate [*N*-(phosphonomethyl)glycine]-resistant cotton was commercially released with the trade name, Roundup Ready, in 1997 (Faircloth et al., 2001; Pline et al., 2001). This technology has been overwhelmingly accepted by producers with more than two-thirds of the 2003 U.S. cotton crop being planted with Roundup Ready seed (Ihrig et al., 2003). More than 95% of the 2003 North Carolina cotton crop consisted of transgenic cotton (USDA-Agricultural Marketing Service Cotton Program, 2003). Glyphosate, a member of the glycine herbicide family, nonselectively controls a broad-spectrum of economically significant grass and broadleaf weed pests by disrupting the shikimic acid pathway (Ellis and Griffin, 2002). The GR weed management system is an effective alternative to conventional methods, requiring less herbicide and fewer applications to produce the same yield and net economic return (Culpepper and York, 1998).

Glyphosate-resistant cotton has been associated with boll abscission, fruit malformation, and yield fluctuations compared to non-GR cotton cultivars (Jones and Snipes, 1999; Pline et al., 2002). Numerous field studies have been conducted including recommended and off-label over-the-top (OT) and postdirected (PD) glyphosate applications to GR cotton for determining injurious rates and timings. Yield losses are only evident in situations where environmental conditions limit resources and do not allow sufficient compensation for fruit loss and underdeveloped bolls (Jones and Snipes, 1999; McCloskey and Moser, 2002).

The current Roundup Ready technology does not provide sufficient gene expression and subsequent glyphosate tolerance in some flower tissues to prevent reduced reproductive efficiency (Pline et al., 2002). Over-the-top glyphosate applications after the four-leaf stage hinder healthy pollen development and pollen deposition creating problems with fertilization, which may consequently accrue yield loss (May et al., 2004; Pline et al., 2002). In addition, Pline et al. (2001) reported that cotton stem tissue absorbed more glyphosate when sprayed PD than OT at four growth stages ranging from four-leaf to 2 wk after first bloom. Subsequent research suggested that reproductive tissues exhibit poor expression of the genes responsible for producing the alternative nonglyphosate binding enzyme, 5-enolpyruvylshikimate-3-phosphate synthase (Pline et al., 2002).

Cotton is a perennial plant, exhibiting indeterminate growth and fruiting habits and is grown as an annual crop, thereby increasing the necessity of intense management for profitable production (Cothren, 1994). Provision of sufficient resources, such as fertilizer and adequate soil moisture, is required to ensure profitable yield. However, these inputs may contribute to excessive vegetative growth, causing low efficiency in plant resource utilization. Plant growth regulators (PGR) alter plant growth with the potential for improving efficient plant resource allocation (Cothren, 1994). Over the past 30 yr, PGRs have been marketed for use in cotton for purposes that vary from increasing seedling vigor, suppressing vegetative growth, and increasing yield.

Mepiquat chloride (1,1-dimethylpiperidinium chloride) is a commonly used PGR in cotton (McCarty and Hedin, 1994). Mepiquat chloride inhibits gibberellic acid

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Abbreviations: a.e., acid equivalent; DD15.5, growing degree day; 4OT, over-the-top at four-leaf stage; 8 non-Prec PD, nonprecision postdirected at eight-leaf stage; 8 Prec PD, precision postdirected at the eight-leaf stage; 8OT, over-the-top at eight-leaf stage; GR, glyphosate-resistant; MC, mepiquat chloride; OT, over-the-top; PD, postdirected; PGR, plant growth regulator.

synthesis, via blocking the cyclization of geranylgeranyl pyrophosphate to copalyl pyrophosphate and also blocks further transformation of copalyl pyrophosphate to ent-kaurene in the gibberellic acid biosynthesis pathway (Halmann, 1990). A common response of cotton treated with MC is reduced internode length, reducing overall plant height (Kerby, 1985; McCarty and Hedin, 1994). Plant growth regulators like MC can inhibit shoot growth and suppress excessive vegetative growth without affecting leaf production and reproductive development (Dicks, 1980; Han, 1991). Although shifts in biomass partitioning from vegetative to reproductive tissue have been documented, yield improvement is not consistently found (Boman et al., 1998; Chaney, 1998). Mepiquat chloride allows producers to regulate vegetative growth to match environmental conditions (Landivar et al., 1996).

The northern portion of the Cotton Belt has a limited growing season and improper glyphosate use in GR cotton may cause a fruiting shift, delaying maturity. Cotton planting date trials in North Carolina show an average lint loss of 13.5 kg ha^{-1} d^{-1} for cotton planted after 5 May (Edmisten, 2004a). Late-planted cotton initiates anthesis later in the growing season causing bolls to develop later, which is usually in cooler conditions (Gormus and Yucel, 2002). The present study tests the hypothesis that variable planting date and use of MC will alter glyphosate-induced reproductive abnormalities. The primary objective was to determine if late-planted cotton responds differently to glyphosate over a range of application timings and methods. The secondary objective included examining how the use of MC according to current North Carolina Extension recommendations affects fruiting compensation in GR cotton.

MATERIALS AND METHODS

Field studies were conducted at the Upper Coastal Plain Research Station near Rocky Mount, North Carolina, in 2001 on Marvyn sandy loam (fine-loamy, kaolinitic, thermic Typic Kanhapludults); in 2002 on Lynchburg fine sandy loam (fine-loamy, siliceous, semiactive, thermic Aeric Paleaquults); and in 2003 on Norfolk loamy sand (fine-loamy, kaolinitic, thermic Typic Kandiudults). Weather data were collected from a State Climate Office of North Carolina weather station located on the research station. Measurements were taken each minute and recorded hourly with a datalogger (Model CR-10X, Campbell Scientific, Logan, UT). Air temperature was measured with a platinum resistance thermometer (Model HMP45C, VAISALA, Helsinki, Finland). Daily growing degree day (DD15.5) units were calculated by subtracting the base temperature of 15.5°C from the average of the daily maximum and minimum temperatures. When temperatures were low enough for the calculation to produce a negative value, DD15.5 accumulation for the day was assumed to be zero.

A factorial treatment arrangement was used with two planting dates and five glyphosate application methods, including one without glyphosate. Treatments were replicated four times and arranged in a randomized complete block design. Optimum planting dates for this study were (1 May 2001, 30 Apr. 2002, 7 May 2003) and late planting dates were (6 June 2001, 4 June 2002, 2 June 2003). Glyphosate application methods were glyphosate OT at the four-leaf stage (4OT), glyphosate 4OT plus glyphosate OT at the eight-leaf stage (8OT), glyphosate 4OT plus glyphosate nonprecision PD at the eight-leaf stage (8 non-Prec PD), and glyphosate 4OT plus glyphosate precision PD at the eight-leaf stage (8 Prec PD). All glyphosate applications were 0.84 kg a.e. ha^{-1} glyphosate. Precision PD applications were made with a hood to prevent spray solution contact with foliage and nonprecision PD applications allowed spray solution contact to the lower 15 cm of plants. The 10 planting date and glyphosate combinations were factored across programs using MC and no-MC as needed equaling a total of 20 treatments in 2001 and 2002.

Cotton cultivar DP 451 B/RR was planted on 91-cm beds. Average plant stands of 135 400, 124 700, and 114 400 plant ha^{-1} were established in 2001, 2002, and 2003, respectively. Plots were four rows wide by 12 m long, and data were obtained from the middle two plot rows. Plots were maintained weed-free to prevent weed–crop competition. Trifluralin (a,a,a-trifluoro-2,6-dinitro-*N*, *N*-dipropyl-p-toluidine) was incorporated before planting at 0.84 kg ha^{-1} and fluorometuron [1,1-dimethyl-3-(a,a,a-trifluoro-m-tolyl) urea] was applied at 1.35 kg ha^{-1} after planting. Decisions on rate and timing of MC applications were based on the Modified Early Bloom method according to North Carolina Extension recommendations (Edmisten, 2004b). Because the use and timing of MC are based on growing conditions, all plots were treated with MC in 2003. Optimal-planted cotton was treated with MC on 29 June 2001 (24.5 g a.i. ha^{-1}), 20 June 2002 (18.4 g a.i. ha^{-1}), 29 July 2002 (24.5 g a.i. ha^{-1}), 7 July 2003 (24.5 g a.i. ha^{-1}), and 17 June 2003 (24.5 g a.i. ha^{-1}). Late-planted cotton was treated with MC on 10 July 2001 (24.5 g a.i. ha^{-1}), 15 Aug. 2001 (49.1 g a.i. ha^{-1}), 29 July 2002 (24.5 g a.i. ha^{-1}), and 17 July 2003 (24.5 g a.i. ha^{-1}).

Plant mapping data were obtained from a six-plant subsample in each plot before harvest each year. Bolls were recorded as to mainstem node and sympodial branch node position. Total bolls on monopodial branches were also counted (Mauney, 1986). Mapping data were used to determine total bolls plant^{-1}, monopodial bolls plant^{-1}, boll distribution by sympodial position, and percentage of total bolls within mainstem Node Zones of 1 to 5, 6 to 10, 11 to 15, and 16 to 20. The cotyledonary scars were considered Node 0. Plots were defoliated and harvested separately by planting date if maturity was different between planting dates. The middle two rows of plots were machine harvested, and seedcotton subsamples were taken from each plot for high volume instrument analysis by Cotton Incorporated, Cary, NC.

Because MC was only a treatment factor in 2001 and 2002, data from these 2 yr were analyzed over years, and 2003 was analyzed separately. Data were analyzed in SAS (Version 9.1) under the general linear model and means were separated using Fisher's Protected LSD at either alpha = 0.05 or 0.10. Treatment effect F tests were performed against their specific error source. In statistical analyses, years were treated as a random source of replication, and year × main effect interactions were ignored when main effects were strong and did not crossover between years (Gomez and Gomez, 1984). Main effect means for 2001 and 2002 were pooled across years and other main factors when interaction was not significant. Data for 2003 were analyzed as a two-factor experiment.

RESULTS AND DISCUSSION

Yield

In the 2001 and 2002 analyses, a significant year × glyphosate × planting date interaction occurred for yield (Table 1). Cotton treated with 4OT + 8OT glyphosate

Table 1. Analysis of variance for main effects and main effect interactions on yield, plant height, nodes, height to node ratio (HNR), first sympodial branch with a retained boll (FSRB), and number of bolls set on sympodial branches in 2001 and 2002 at Rocky Mount, North Carolina.

						Sympodial positions				
Source	Yield	Plant height	Nodes	HNR	FSRB	First	Second	Outer	Monopodial	Total
				2001 and 2002						
Year	**	***	**	*	**	NS	NS	NS	NS	NS
MC	NS	***	***	***	***	*	NS	NS	†	NS
Year × MC	**	***	***	***	*	NS	NS	NS	NS	NS
Glyphosate (GLY)	**	NS	†	NS	NS	**	*	*	†	NS
Year × GLY	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MC × GLY	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Year × MC × GLY	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Planting date (PDATE)	***	***	***	***	***	*	*	NS	***	***
Year × PDATE	***	NS	NS	NS	NS	***	***	***	***	***
MC × PDATE	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Year × MC × PDATE	NS	NS	NS	NS	**	NS	NS	NS	NS	NS
GLY × PDATE	*	NS	NS	NS	NS	NS	NS	NS	NS	NS
Year × GLY × PDATE	*	NS	NS	NS	NS	NS	NS	NS	NS	NS
MC × GLY × PDATE	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Year × MC × GLY × PDATE	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
				2003						
GLY	NS	*	*	NS	NS	NS	NS	*	†	NS
PDATE	**	**	*	**	NS	*	†	*	†	**
GLY × PDATE	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
† Significant at the 0.10 probability level.

in 2001 had lower yield than all other glyphosate application methods in both planting dates (Table 2). In a similar study by Jones and Snipes (1999), they reported consistent yield losses when GR cotton was treated with glyphosate OT at five- or six-leaf stages. In 2002, yields did not differ among glyphosate methods at the optimal date, but the 4OT + 8 non-Prec PD and 4OT + 8OT applications of glyphosate, had lower yield than the untreated cotton in the late-planting date of 2002. The yield reduction in response to nonprecision PD application in late-planted cotton suggests that an application does not have to be later than four-leaf and OT to cause significant yield loss, if the environmental conditions are not favorable for fruiting compensation. This response brings further light to previous findings on cotton's absorption properties of glyphosate where it was demonstrated that higher amounts of glyphosate are absorbed through the stem compared to leaves (Pline et al., 2001). Thus, nonprecision PD applications made after the four-leaf stage are potentially more hazardous than OT applications at the same growth stage. Glyphosate did not affect cotton yield in 2003.

Previous reports concerning glyphosate use in GR cotton are reconfirmed by the yield results in this study. Glyphosate application OT after the four-leaf stage resulted in yield loss (Vargas et al., 1998), but not consistently over years (Kalaher and Coble, 1998). Glyphosate applications made in accordance with label recommendations never affected yield in the current study. The absence of yield loss for off-label glyphosate application in optimal-planted cotton in 2002 and both optimal- and late-planted cotton in 2003 suggests the existence of compensatory reproductive growth under favorable environmental circumstances (Ferreira et al., 1998; Kalaher and Coble, 1998; Jones and Snipes, 1999). Previous research has shown no yield loss with off-label applications compared to GR cotton not treated with glyphosate (Ferreira et al., 1998; McCloskey and Moser, 2002).

Table 2. Effect of glyphosate application method and planting date on seedcotton yield in Rocky Mount, North Carolina.

	2001‡		2002		2003	
	Planting date					
Glyphosate† application method	Optimal§	Late	Optimal	Late	Optimal	Late
	kg ha^{-1}					
None	4050 Aa#	1870 Ab	2010 Aa	2040 Aa	3330 Aa	2640 Ab
4OT¶	4060 Aa	1810 Ab	2400 Aa	2110 Aa	3210 Aa	2550 Ab
4OT + 8 Prec PD	4050 Aa	1900 Ab	2450 Aa	1990 ABa	3380 Aa	2100 Ab
4OT + 8 non-Prec PD	3900 Aa	1700 Ab	2600 Aa	1700 Bb	3410 Aa	2640 Ab
4OT + 8OT	3240 Ba	1120 Bb	2280 Aa	1000 Cb	3300 Aa	2100 Ab

† Each glyphosate application was 0.84 kg a.e. ha^{-1}.
‡ Data for 2001 and 2002 are pooled across MC and are separated by planting date to show the year × glyphosate × planting date interaction.
§ Optimal-planting dates were 1 May, 30 Apr., and 7 May, in 2001, 2002, and 2003, respectively. Late-planting dates were 6, 4, and 2 June, in 2001, 2002, and 2003, respectively.
¶ 4OT, 4-leaf over-the-top; 8 Prec PD, 8-leaf precision postdirect; 8 non-Prec PD, 8-leaf nonprecision postdirect; 8OT, 8-leaf over-the-top.
\# Means followed by the same uppercase letter within a column are not statistically different and means followed by the same lowercase letter within a row in the same year are not statistically different according to Fisher's Protected LSD at alpha = 0.05.

Mepiquat chloride improved seedcotton yield in 2001 by 280 kg ha^{-1} or 11%, but did not affect yield in 2002 (data not shown). Cotton planted 1 May in 2001 yielded 56% or 2180 kg ha^{-1} more seedcotton than cotton planted 2 June that year over all glyphosate and MC treatments. In 2003, cotton planted 7 May produced 930 kg ha^{-1}or 28% more seedcotton than cotton planted 2 June that year. Planting date effects on yield for 2002 were only associated with off-label glyphosate applications that caused an average of 45% loss. Gormus and Yucel (2002) and Guthrie (1991) reported a yield loss with delayed planting in cotton for three planting dates and concurred that more days were required to reach maturity for each later planting date.

Early cool temperatures in 2001 stopped boll development, and contributed to yield loss in later maturing cotton, including late-set bolls in cotton not treated with MC. Accumulated DD15.5 for individual planting date and year are displayed in Fig. 1. The 2001 season produced the highest and lowest yield observed in this study. An early plateau of DD15.5 accumulation started 26 Sept. 2001 and was associated with an early frost (9 Oct. 2001) causing crop termination. This onset of cooler temperatures was 148 and 112 DAP, respectively for optimal- and late-planted cotton in 2001, contributing to the drastic effect of planting date on yield.

Growth Characteristics and Boll Distribution

Growth measurements taken during plant mapping suggest that late-planted cotton has greater vegetative growth. Cotton planted late was 10 cm taller in 2001 and 2002, and 23 cm taller in 2003 compared with optimal-planted cotton (Table 3). Optimal-planted cotton in 2001 and 2002 had more nodes than late-planted cotton while the opposite was true in 2003. Height-to-node ratio was greater for late-planted cotton in all years. Cotton planted at optimal dates in 2001 and 2002 set the first boll an average of one mainstem node lower than late-planted cotton. These results are in accordance with previous findings where late planting was associated with more vegetative growth (Cathey and Meredith, 1988).

Glyphosate applied 8 non-Prec PD and 8OT in 2003 caused plants to be shorter than plants treated 8 Prec PD (Table 4). Glyphosate application of 8OT had an average of 0.6 more nodes plant^{-1} than cotton in other glyphosate treatments in 2001 and 2002. In 2003, cotton treated with glyphosate after the four-leaf stage had an average of 1.1 more nodes than untreated cotton. Height-to-node ratio was not affected by glyphosate in 2001 and 2002, but the combined effect of shorter plants and more nodes in cotton treated with 8 non-Prec PD and 8OT glyphosate in 2003 resulted in shorter average internodes compared to cotton not receiving glyphosate. The increase of node initiation with more glyphosate contact to plant tissue at the eight-leaf stage indicates a reversion to vegetative growth due to reduced boll load on lower nodes.

Response to MC was consistent with previous reports showing reduced plant height and internode length (Kerby, 1985; York, 1983). Use of MC in 2001 and 2002 contributed to plants being an average of 21 cm shorter, producing 1.4 fewer nodes, and having an average of 0.8 cm shorter internodes (Table 5). Mepiquat chloride shifted initial fruit retention almost a full node lower in late-planted cotton in 2001. This result suggests that an occasional benefit of earlier fruit set with MC may contribute to earliness in short-season conditions. First-position bolls are considered the largest contributors to yield (Mauney, 1986), however, in this study, plants treated with MC had fewer first-position bolls and this result did not affect yield.

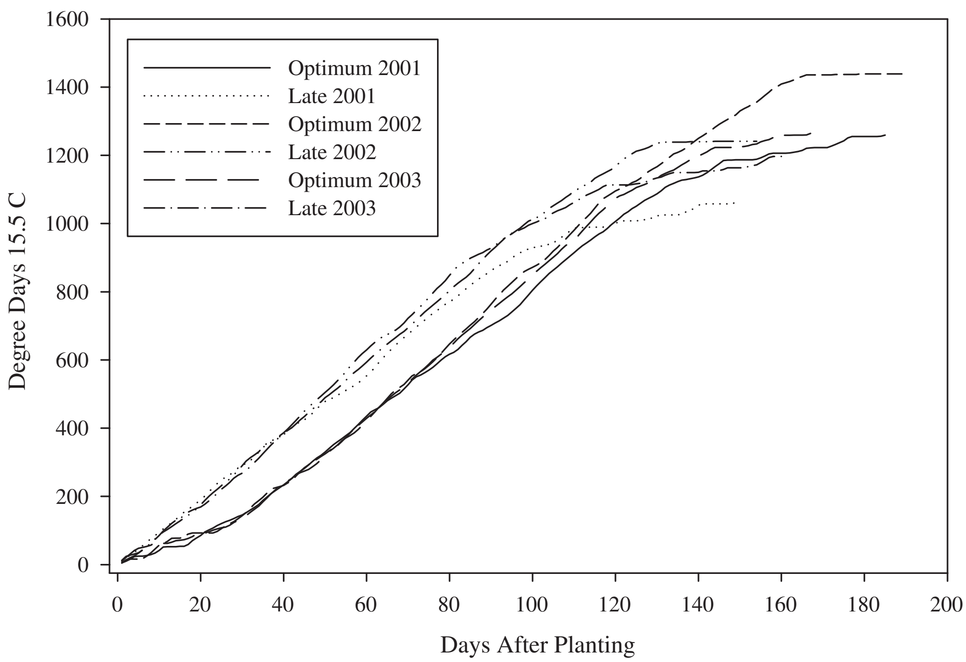

Fig. 1. Accumulated growing degree days from day of planting for each planting date and year combination.

Table 3. Effect of planting date on plant height, nodes, height to node ratio (HNR), and first sympodial branch with a retained boll (FSRB) at Rocky Mount, North Carolina.

Planting date†	Plant height		Nodes		HNR		FSRB	
	2001 and 2002‡	2003§	2001 and 2002	2003	2001 and 2002	2003	2001 and 2002	2003
	cm		plant^{-1}		cm node^{-1}			
Optimal	80***	69**	18.3***	16.9**	4.4***	4.1**	6.1**	6.7
Late	90	92	17.5	18.3	5.1	5.0	7.1	6.8

** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
† Optimal-planting dates were 1 May, 30 Apr., and 7 May, in 2001, 2002, and 2003, respectively. Late-planting dates were 6, 4, and 2 June, in 2001, 2002, and 2003, respectively.
‡ Data for 2001 and 2002 are pooled across MC and glyphosate application methods.
§ Data for 2003 are pooled over glyphosate application methods.

Although MC increased yield in 2001, it did not affect production of total bolls plant^{-1} in 2001 or 2002 (data not shown). Glyphosate application did not affect total bolls plant^{-1} (data not shown). Boll mapping data were grouped into Node Zones and are reported as percentage of total boll load to detect mainstem positioning of the crop as affected by the treatments (Table 6). Optimal-planted cotton initiated and retained the highest portion of the boll load (60 and 58%, respectively) on sympodial Nodes 6 to 10 in 2002 and 2003, while late-planted cotton produced the majority of the crop on or above Node 11 in all years (data not shown). In 2003, late-planted cotton had 7% more bolls located in Node Zone 16 to 20 compared to optimal-planted cotton.

Jones and Snipes (1999) reported an overall decrease in boll retention for cotton treated with glyphosate at five- and six-leaf stages compared to untreated cotton, although yield was not affected. In this study, glyphosate applications of 4OT + 8OT decreased the percentage of bolls set on sympodial Nodes 6 to 10 by 10% compared to cotton not having foliar glyphosate contact after the four-leaf stage in 2001 and 2002 but increased bolls numbers in Node Zone 11 to 15. Because glyphosate did not affect total boll numbers, this shift of boll location is directly related to the negative yield response observed in 2001 and late planted cotton in 2002 to glyphosate. In 2001, it is likely that optimal-planted cotton with 4OT + 8OT glyphosate would not have suffered yield loss without the early fall. Glypohsate did not affect the distribution of bolls in 2003, and did not affect yield. Pline-Srnic et al. (2004) reported variable results including fewer bolls on Nodes 1 to 10 in GR cotton treated with glyphosate at the seven-leaf stage compared to untreated GR cotton.

Mepiquat chloride caused more bolls to be set lower in the fruiting profile compared to untreated cotton. In 2001, 2 and 17% more bolls were located in Node Zones 1 to 5 and 6 to 10, respectively, for cotton treated with MC compared to untreated cotton. Cotton not treated with MC produced 14% more of its sympodial bolls on Nodes 11 to 15 compared to cotton treated with MC in 2001. The positive yield response in 2001 to MC is supported by these boll numbers. In 2001 and 2002, cotton not treated with MC produced 4% more of the crop on or above Node 16 compared to MC-treated cotton. Mepiquat chloride did not affect boll load in 2002 below Node 16, and a yield response to MC was not observed that year. A shift in boll load toward the upper portion of the plant, as with late planted cotton in this case, would not favor early maturity, and can negatively affect yield as described by Zhao and Oosterhuis (2000).

Fiber Quality

Fiber quality was not affected by planting date or glyphosate application method in 2001 or 2002 (data not shown). It appears that although glyphosate caused upward shifts in mainstem boll location and some yield loss; however, the bolls that remained and were harvested developed normally and were not affected by glyphosate. There were no differences in micronaire reading with MC in cotton planted at optimal dates; however, late-planted cotton was affected variably between years. In 2001, MC increased the average mi-

Table 4. Effect of glyphosate application method on plant height, nodes, height to node ratio (HNR), and first sympodial branch with a retained boll (FSRB) at Rocky Mount, North Carolina.

Glyphosate† application method	Plant height		Nodes		HNR		FSRB	
	2001 and 2002‡	2003§	2001 and 2002	2003	2001 and 2002	2003	2001 and 2002	2003
	cm		plant^{-1}		cm node^{-1}			
None	85 a#	81 ab	17.6 b	16.8 c	4.8 a	4.8 a	6.7 a	6.4 a
4OT¶	85 a	81 ab	17.9 b	17.5 bc	4.7 a	4.6 ab	6.6 a	6.7 a
4OT + 8 Prec PD	83 a	86 a	17.8 b	17.7 ab	4.7 a	4.8 a	6.5 a	7.0 a
4OT + 8 non-Prec PD	86 a	77 b	17.8 b	18.3 a	4.8 a	4.2 b	6.5 a	6.8 a
4OT + 8OT	87 a	73 b	18.4 a	17.7 ab	4.8 a	4.3 b	6.8 a	6.7 a

† Each glyphosate application was 0.84 kg a.e. ha^{-1}.
‡ Data for 2001 and 2002 are pooled across MC and planting dates.
§ Data for 2003 are pooled across planting dates.
¶ 4OT, 4-leaf over-the-top; 8 Prec PD, 8-leaf precision postdirected; 8 non-Prec PD, 8-leaf non-precision postdirected; 8OT, 8-leaf over-the-top.
# Means followed by the same letter within a column are not statistically different according to Fisher's Protected LSD at $\alpha = 0.05$.

Table 5. Effect of MC on height to node ratio (HNR) and first sympodial branch with a retained boll (FSRB) in 2001 and 2002 at Rocky Mount, North Carolina.

				FSRB			
				2001		2002	
				Planting date			
Plant growth† regulator	Plant height‡	Nodes	HNR	Optimal	Late	Optimal	Late
	cm	plant^{-1}	cm node^{-1}				
None	96***	18.6***	5.2***	6	7.3**	6.5	7.3
MC	75	17.2	4.4	5.8	6.4	6.3	7.4

** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
† MC rates and application timings were according to North Carolina Extension recommendations for the Modified Early Bloom method.
‡ Data are pooled across planting date and glyphosate application methods.

cronaire reading for late-planted cotton from 3.05 to 3.36 and lowered the reading from 4.47 to 4.21 in late-planted cotton in 2002 compared to untreated cotton. In 2003, optimal-planted cotton had a micronaire reading of 4.12, compared to 3.37 for late-planted cotton that year. In environments producing high and low micronaire readings with the same cultivar, the MC program improved micronaire readings to more acceptable ranges. Mepiquat chloride marginally improved fiber length from 27.8 to 28.1 mm and fiber strength from 267.7 to 272.6 kN m kg^{-1} in 2001 and 2002. Mepiquat chloride has some affect on maturity, and it can also affect fiber quality in relation to harvest timing and weather conditions (Zhao and Oosterhuis, 2000).

CONCLUSIONS

Managing the current GR cotton technology in conjunction with nonprecision PD or OT glyphosate applications after the four-leaf stage can result in yield losses, especially in late-planted cotton. Adverse results from using glyphosate in GR cotton are not eminent, however, they are more probable when glyphosate applications are not made strictly according to label recommendations. The results of this study show that glyphosate contact after the four-leaf stage can cause loss of fruit in the lower portion of the fruiting profile and may result in a fruiting shift toward the upper portion of the plant. This is more noticeable when applications are made OT compared to PD. These upward shifts in fruiting make planting date and the remainder of the growing season even more important, because later set bolls have a greater potential of not reaching maturity.

Cotton under the MC program did not experience any decrease in quality or yield. In fact, when differences associated with MC were found, they were in favor of improving the yield and quality of the crop. Use of MC, in this case, provided retention of a higher portion of the crop in the lower part of the fruiting profile, which may result in early maturity. This suggests that the Modified Early Bloom method for MC recommendations works reliably in North Carolina. The optimal window in the northern region of the cotton belt is narrow between the time when conditions favor emergence and vigorous seedling growth, thus planting in this window should be given priority. The findings of this study show the additive effect that incorrect management decisions may have on the production of GR cotton, however, it provides further guidance for avoiding situations where losses are more probable.

Table 6. Analysis of variance for main effects and main effect interactions on the percentage of total bolls distributed by Node Zone at Rocky Mount, North Carolina.

	Node zone†			
Source	1–5	6–10	11–15	16–20
2001 and 2002				
Year	*	NS	NS	NS
MC	NS	***	***	***
Year × MC	NS	**	***	NS
Glyphosate (GLY)	*	**	*	NS
Year × GLY	NS	NS	NS	NS
MC × GLY	NS	NS	NS	NS
Year × MC × GLY	NS	NS	NS	NS
Planting date (PDATE)	NS	**	***	NS
Year × PDATE	NS	*	NS	NS
MC × PDATE	NS	NS	NS	NS
Year × MC × PDATE	NS	NS	NS	NS
GLY × PDATE	NS	NS	NS	NS
Year × GLY × PDATE	NS	NS	NS	NS
MC × GLY × PDATE	NS	NS	NS	NS
Year × MC × GLY × PDATE	NS	NS	NS	NS
2003				
Glyphosate (GLY)	NS	NS	NS	NS
Planting date (PDATE)	NS	*	**	*
GLY × PDATE	NS	NS	NS	NS

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
† Node Zones are groups of five consecutive nodes considering the cotyledonary scar as Node 0.

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